INTERPRETING PHYSICS TEACHERS' FEEDBACK COMMENTS ON STUDENTS' SOLUTIONS TO MOTION TASKS

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ABSTRACT

This paper investigates teachers' intentions, when providing their feedback comments to hypothetical students' written solutions to linear motion tasks. To obtain an in-depth understanding of the teachers' thinking when responding to student written solutions, a qualitative case study approach was employed using two different data sources: a Problem Centred Questionnaire (PCQ) and a Problem Centred Interview (PCI). Data processing was conducted in two main phases: Initial and Comparative. In both phases we explored patterns about teachers' foci across student strategies and motion tasks. A main finding of this research is to categorising teachers' interpretations and feedback on student solutions, based on the extent of teachers' attentions to Student Thinking and Disciplinary Thinking. This analysis approach refines the previously held view that a high level of teacher content knowledge, and a concurrent focus to both 'student thinking' and 'disciplinary thinking' are required to provide meaningful feedback on student solutions. The findings indicated that their level of teachers' propositional knowledge, or their teaching experience were less strongly associated with the nature of their feedback to student difficulties, than with the nature of teachers' beliefs about teaching and learning motion.

1. INTRODUCTION

It has been widely reported in literature that students at both secondary school and tertiary levels have difficulty understanding physics concepts involving problem solving in kinematics (e.g. velocity, acceleration, displacement) (e.g., di Sessa, 1993; Driver, Squires, Rushworth & Wood-Robinson, 1994; McDermott, 1993; Redish& Steinberg, 1999; Shaffer & McDermott, 2005). Noteworthy are the kinds of difficulties the students struggle with, which include the nature of motion tasks and application of mathematics and formulae in motion tasks. Hence, the authors recommend that physics teachers should be more knowledgeable about the sources of student difficulties in physics. For instance, regarding the difficulty associated with the nature of motion tasks students face challenges when solutions conflict with real life experience. Often students tend to apply common-sense understandings to the problem situations, which oftentimes is in conflict with the physics of the situations. And, with regard to application of mathematics and formulae in motion tasks, it is common practice among many students to attempt to solve the problem tasks using mathematical substitution without understanding the underlying physics principles. Therefore, it makes great pedagogical sense for a teacher to interpret the students' approaches and construct formative feedback that will appropriately nudge the students toward better solutions consistent with their chosen approaches/strategies. Hence the current study aims to explore physics teachers' thinking about, when providing feedback on, student learning difficulties in solving linear motion tasks, as guided by the following research questions:

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- What are physics teachers' foci, when they provide comments on students' *correct* and *incorrect* solutions?

- How do physics teachers' suggested feedback relate to their knowledge?

2. BACKGROUND

The studies about science teachers (e.g. Sanders, Borko, &Lockard, 1993) suggest that teacher content knowledge generally underpins their feedback on student difficulties in science. Others, for example Magnusson, Krajcik and Borko (1999) suggest that teacher dispositions or beliefs about how students learn and about effective teaching approaches to a specific topic have the capacity to influence teachers' feedback in a particular context. Teachers themselves are often assumed to have a rich content knowledge which is often seen as necessary for developing and using teaching approaches that promote student understanding, a point that will be explained later in this paper.

Kagan (1990) noted the prominent position of problem solving as a teaching and learning approach in physics. Other literature (e.g., Clement, 1994; Sherin, 2001) suggested that student understanding of the formulae used in physics is necessary to solve problems with understanding, which in this paper could be considered meaningful problem solving strategy. According to Redish (1994), rather than teaching solving problems in a rote way, teachers should have belief in and commitment to designing and delivering instruction basing on students' prior knowledge and dispositions.

Thus the study employed a constructivist view of conceptual change which according to Duit et al. (2007), deliberately accounts for students' pre-instructional understandings in interpreting teachers' intentions or beliefs embedded in their feedback on students' written solutions to linear motion tasks. This is consistent with conceptual change instruction, which tends to generally place value on the ideas about physics phenomena that students bring to class.

3. THEORETICAL FRAMEWORK

This study employed conceptual change perspective (Posner et al., 1982; Duit et al., 2007) in tandem with three perspectives of feedback including feature (Bloom & Bourbon, 1980; Shute 2008), presentational (Nelson &Schunn, 2009; Hmelo-Silver & Barrows, 2006) and functional (Black & William, 1998; Ellis, 2009). While conceptual change served as the umbrella framework for interpreting the teachers' feedback to students' conceptions in physics, the three feedback perspectives were very important in understanding the physics teachers' feedback to students' motion tasks solutions.

As discussed by Bloom and Bourbon's (1980) typology for teacher feedback and highlighted further by Shute (2008) and Kulhavy and Stock (1989), feedback comprises two components: verification and elaboration. Verification involves a decision on whether or not the student response is correct while elaboration involves indication of clear justification for the response (indication of the way things happened (how), causes of (what), and the reason or explanation for their response (why). Black and William (1998) have analysed the presentational perspective and also identified two feedback components: directive and facilitative, which involve pointing out to students what to correct and offering hints or suggestions respectively. Others including Nelson and Schunn (2009) and Hmelo-Silver and Barrows (2006, 2008) have described perspectives for analysing more complex teacher feedback. Nelson and Schunn (2009), using peer feedback, highlight the importance of argumentation and interpretation, which comprise affective and cognitive elements (summarization, feedback specificity, explanations, and scope). And, as for

Hmelo-Silver and Barrows (2006) facilitation strategies, which are conveyed in feedback, especiallyin problem-based learning situations, are critical. These include open-ended and meta cognitive questioning or probing including seeking warrants for claims, causations and backings.

The perspectives highlighted above were employed in this study to investigate and interpret teacher thinking, intentions or beliefs imbedded in eleven Australian upper secondary school physics teachers' feedback on hypothetical students' written solutions to linear motion tasks. Kagan (1990) defined teacher thinking in terms of "beliefs and knowledge about teaching, students, and content; and/or awareness of problem-solving strategies endemic to classroom teaching" (p. 421). An investigation of teacher beliefs about effective teaching approaches for teaching problem solving in the physics topic of motion were part of the investigation of teacher intentions. In other words, the use of problem solving as a goal and a method was chosen to explore teachers' socially situated intentional or skilled thinking. This is consistent with social ontological approaches Kagan (1990) suggested for exploring teachers' cognition including "ulti method evaluations of teachers' pedagogical content knowledge" and "taxonomies used to assess teachers' self- reflection and awareness of problem-solving strategies" (p. 422). In all these perspectives were applied through the lens of Ricoeur's theory of interpretation (Ghasemi, Taghinejad, Kabiri& Imani, 2011; Tan, Wilson, & Oliver, 2009), which is discussed later under the analytical theory.

4. METHODOLOGY

A qualitative approach was chosen to produce detailed analysis information (Patton, 2002) about the selected teachers' thinking, intentions or beliefs imbedded in their written feedback on students' written solutions to linear motion tasks. The approach adopted enabled the design of appropriate instruments, including a Problem Centred Questionnaire (PCQ) and a Problem Centred Interview (PCI) to respond to the particular research questions. More detailed information about collecting the data is outlined below.

4.1. Data Collection

Twenty secondary physics teachers from metropolitan Melbourne schools were invited to participate in the interview. To be selected the teachers had to meet the following criteria: be qualified to teach or have teaching experience in high school, and were currently teaching Victorian Certificate of Education (VCE) physics; be able to teach maths and physics subjects; willing to work with a group of teachers who had a range of seniority in teaching. Since there was need to select only the teachers who meet the criteria, it was necessarily required to use a purposeful sampling technique. It is important to conduct a purposeful sampling technique, because"… it serves the real purpose and objectives of the researcher of discovering, gaining insight into, and understanding a particularly chosen phenomenon" (Burns, 2000, p. 465). In purposeful sampling, information-rich cases are studied to illuminate the research question (Patton, 2002). The conversations and interview with each physics teacher led to eleven case studies of physics teachers' skilled or intentional knowledge. The eleven selected physics teachers were teaching at a number of different secondary schools in Melbourne, Australia and their experiences ranged from 3 to 35 years of teaching physics in secondary schools. To address the research questions and exploring the significant components of teachers' knowledge a Problem Centred Questionnaire (PCQ) and a qualitative Problem-Centred Interview (PCI) were designed (Parvanehnezhadshirazian, 2011). These two instruments were useful to facilitate the explorations of the interplay of teachers' inductive and deductive thinking, and this could inform the researchers' knowledge of the physics teachers' approaches to solve and teach different motion tasks (see relevant sections of PCQ in Appendix A).

The process of designing the instruments included selecting several linear motion tasks, and then having a selection of these problems solved by students from high schools in Melbourne, and also some first year university physics students from The University of Melbourne. The difficulties experienced by these participants in solving kinematics tasks were similar to student difficulties in using mathematics in physics, as identified previously in the Introduction section. In order to select the items for the PCQ and PCI, different kinds of solutions to the standard motion tasks (See Figure 1) from the 2007, Year 12 physics exam in Victoria. These solutions included student difficulties in understanding kinematics equations and taking a meaningful approach in solving the motion tasks in the items. In order to explore teachers' intentions embedded in their written comments, some *written solutions*(See Appendix A) drew on the aforementioned pilot study of high school and university physics student solutions to linear motion tasks. The dialogue of some *hypothetical student* responses included in the study design, also originated from the pilot study.

Fred is riding his bike on a level road at a speed of 5.0 m s^{-1}. The tail-light break is off. It takes 0.45 seconds to reach the ground. Mary was watching Fred and saw the tail-light fall. Her view of the events is shown in the Figure below. How far above the ground was the tail-light when it was attached?

Fred was at position A when the tail-light broke off, and at position B when it hit the ground.

Fig.1 Bike task (Standard task).

While there were more tasks and items in the PCQ and PCI than the items reported here, this paper discusses the physics teachers' comments on only Chris' and *Rob's* written solutions (see two figures in Appendix A) to a standard task called Bike task (see Figure 1). In the PCQ, each teacher was asked (see Appendix A) to provide a written discussion of, and feedback on, Chris' and *Rob's* written solutions and explanations of their problem solving strategies to the Bike task selected from the 2007, Year 12 physics exam in Victoria, Australia. The Bike task can be easily solved through the use of algorithms, called a standard task. The discussions and strategies of *Rob's* and Chris' solutions, while solving the Bike task are thus analysed to respond to the study's objectives. For instance, *Rob* used rote manipulation and employed the "recursive plug and chug approach" (Tuminaro, 2004) to solve the Bike task. He incorrectly considered the final velocity, $V_f=0$. But Chris had a high/reasonable level of understanding of the formula and solving the physics task.

4.2. Data Analysis

In the current study, grounded theory approach and qualitative content analysis were employed. In this regard, reference to Kagan (1990), Flick (2006), and Mayring (2000) for general accounts of content analysis but more particularly the work of Schwarz, Leung, Buchholtz, Kaiser, Stillman, Brown, et al.(2008),were employed for their use of qualitative content analysis that applied to mathematical modelling. A "qualitative content analysis" approach that represented an "empirical, methodological controlled analysis of texts within their context of communication" was employed to discern the "themes and main ideas of the text" (Mayring, 2000, p. 2). Thus, through qualitative content analysis of teachers' written responses, the main ideas and intentions of each teacher has been identified. Following the analysis of the PCQ, a PCI approach has been conducted. This interview comprised a set of guiding questions to lead discussion questioning and re-questioning in a face-to-face conversation. We developed deeper understanding of the interviewee's views, through indirect questioning, discussion, and gradual communication, to address the research questions (Witzel, 2000). The teachers' responses to the PCI questions were subjected to qualitative content analysis to determine teachers' intentions regarding their comments on student solutions to motion tasks. To achieve additional insights into teachers' understandings of linear motion task and teaching strategies, their personal problem solving strategies, and teaching approach to different tasks have been examined. The methodology used surrogate student solutions in the current study. While this offered practical and logical advantages such as developing these surrogates to cause teachers to engage in deeper reflections and formulate feedback they considered meaningful, it also had practical limitations including the seemingingly teacher artificial feedback that was not based on real time classroom discussions with their students.

4.3. Analytical Theory and Analytical Units

We employed to a large extent Ricoeur's theory of interpretation (Ghasemi, Taghinejad, Kabiri& Imani, 2011; Tan, Wilson, & Oliver, 2009) to make sense of the teachers' feedback to students' standard task solutions. The teachers' feedback, which was in text format, was in a way a response to how they interpreted the students' solutions. Thus, in a way we were dealing with second order hermeneutics. According to Ghasemi et al. (2011), interpreting text can be accomplished at three levels: 1) explanation, 2) understanding, and 3) appropriation. At the first level (explanation) the interpreter explores which text tells something – in Tan et al.'s view, "words [are] … taken at face meaning, and no attempt … [is] made to interpret" (p.10); at the second level (understanding), the interpreter explores which text speaks about something – searching for commonality or differences and thus categorizing or grouping those with common meanings (Tan et al., 2009) or what Luborsky (1994) calls thematic analysis; and at the third level (appropriation), the interpreter appropriates the text for themselves, i.e., forms perceptions or knowledge or as Ricoeur (1981) is cited in Tan et al. (2009) says, "interpretation of text culminates in the self-interpretation of a subject" (p. 8). According to Tan et al. (2009) this is in-depth understanding and suggest "it involves moving back and forth between explanation (level 1) and understanding (level 2) creating what is a hermeneutic arc. Thus, in Tan et al.'s view this process is informed by areas of knowledge that include the interpreter's experiences and beliefs.
Initially the analysis involved comparing the teachers' written comments on student solutions to identifying and interpreting any emergent patterns or regularities. This initial analysis involved a grounded theory approach (Flick, 2006; Kagan, 1990). The detailed analysis of teacher comments on the student solutions helped to adjust the themes discerned at the macro level, which in turn allowed further examination of teacher thinking or the perspectives embedded in their comments. This resulted in two main groups (groups A and B), in terms of a teacher focus and the elements emphasised. Group A is more oriented towards a *content-centred* perspective, as seen in traditional teaching. Group B is more oriented towards a *student-centred* perspective. The implications arising from some of the literature (e.g., Redish, 1994) were taken into account to explore the extent to which teachers placed emphasis on what they themselves wanted students to learn, or placed emphasis on predicting student pre-instructional knowledge and/or on justifying student interaction with and response to the content. The physics teachers in this study seemed to have a perspective that attended predominantly on the learning process as key to learning and applying content, or focused on content as central to learning content application, or focused on both perspectives. However, neither of these perspectives was taken on their own to characterize good teaching. Such teaching is dependent on how a teacher's approach integrates both responsibilities in different situations

It is important to note that the perspectives are not static, but that they are dynamic, because it was not uncommon that a teacher, who had a Student Thinking focus on student X, used a

Disciplinary Thinking focus on student Y. Therefore, the attention/focus that a teacher presented depended on student solutions. It was also possible that a teacher's comment had a focus on either Student Thinking or Disciplinary Thinking category, or on both Student Thinking and Disciplinary Thinking.

In the context of this study, *Disciplinary Thinking*(DT) and *Student Thinking* (ST)are two basic codes, designated by Flick (2006) as "coding families", and "these coding families are sources for defining codes and at the same time orientation for searching for new codes for a set of data" (p. 302). The analysis of the data revealed three subcategories for ST and DT, which were addressing the research questions, with a focus on the use of formula and solving the tasks (see Appendix B).

4.4. Orientation Subcategories of ST and DT Codes

The data that emerged from teacher feedback showed that the teachers provided feedback about the content used in the problem solving strategy, as well as the process or strategy used for problem solving, or the use of the formula. This kind of feedback may have attended to ST and/or DT. In some cases a teacher justified the importance of his/her feedback with an attention to the categories of either ST or DT or both. For these reasons, three subcategories for "basic codes" (Flick, 2006, p. 302) were used for teacher feedback, described as: Description of the feedback in terms of the Content used in problem solving (DT/ C/ P.S), or the use of formula (DT/ C/ Eq);Description of feedback in terms of the Process used in problem solving (DT/ P/ P.S), or the use of formula (DT/ P/ Eq); and Teacher Justification of their suggested feedback, when doing problem solving (DT / J /P.S) or using the equation (DT / J /Eq). Similarly, description and examples of teacher's feedback with a focus on student (ST) was characterized as: the Content used in the problem (ST/ C/ P.S), or the equation (ST/C / Eq); *t*he Process of problem solving (ST/ P / P.S) or understanding the equation (ST/ P / Eq); and Justification of teacher's suggested feedback, when doing problem solving (ST / J /P.S) or using the equation (ST / J /Eq). Detailed examples of coding system are shown in Appendix B. It was possible to characterise a teacher by looking across all her/his comments. The teachers' written and verbal comments were analysed across the DT and ST categories. Some teachers' responses were more extensive and comprehensive than others. Through the initial coding and analysis, each teacher's comments were reduced, coded, summarised, and then presented. An example of summarising a teacher's feedback on eight students' solutions is shown in Appendix C.

5. RESULTS

Responses from eleven physics teachers to the PCQ and PCI were analysed and reported in two sections: (1) teachers' backgrounds derived from the questionnaire, (2) teachers' feedback on student solutions. To consider the confidentiality of all teachers who participated in this research and keep their anonymity, instead of teachers real names, pseudo names have been used throughout this paper. This research was part of an ongoing project and took about four years to conduct the research and finalise the finding reported in this paper.

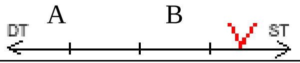
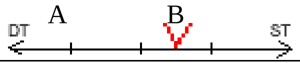
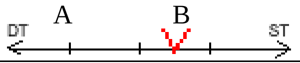
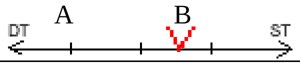
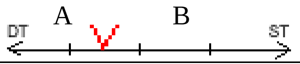
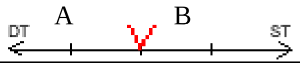
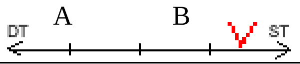
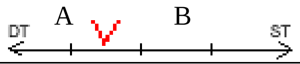
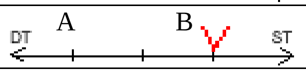
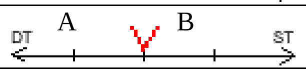
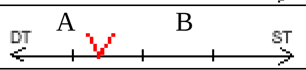
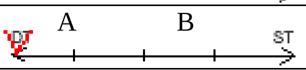
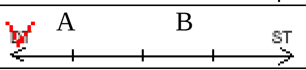
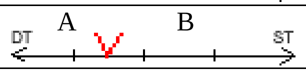
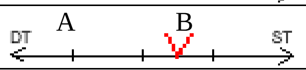
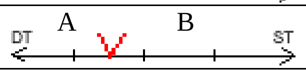
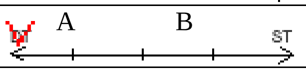
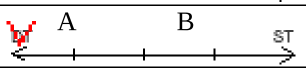
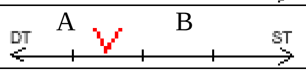
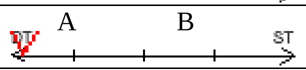
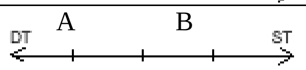
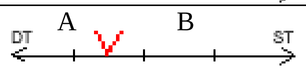
5.1. Teachers' Backgrounds

Investigating teachers' personal strategies in solving linear motion tasks, allowed us to investigate teachers' proficiency and knowledge in solving standard and non-standard motion tasks in the context of linear motion. This investigation was based on an exploration of the teachers' conceptual understandings of motion concepts and the process of problem solving they employed. Out of eleven teachers with varied teaching experiences in the area of maths and physics, only five (Mr Peterson, Mr Robinson, Ms Jenkins, Ms Chick, and Ms Johnson) solved all linear motion tasks successfully, was indicative of their rich content knowledge in the context of linear motion. Although the teachers who did not solve the same tasks appeared to have an in adequate background in the area of those tasks, they may have had a rich background and understanding in other areas of physics. However, considering the length (9 - 20 years) of the teachers' experiences (Mr Pierce, Mr Richardson, Mr Geraldton, Mr Sadler, Ms Jones, and Mr Jackson) in teaching physics, it seems likely that they were able to solve only the standard tasks successfully because they had taught these tasks for a long time, and had often seen them explained in text books. This might be consistent with Arzi& White(2008) findings that show teacher subject matter knowledge does not necessarily develop over time or with experience in teaching.

5.2. Teachers' Feedback on Chris's Correct and Rob's Incorrect Solution

The foci of each teacher's response were identified and discussed by inspection and analysing a word, a phrase, a sentence, or a paragraph or whole teacher comments to a student. It was possible to give a label to a teacher by inspecting across all teachers' comments. Analysis of the teachers' written feedback on student solutions revealed the teachers' thinking, intentions or beliefs. This led to exploring and identifying each teacher's foci, which was summarised (see an example of feedback summary in Appendix C).Based on these summaries teachers feedback on *Chris's* and *Rob's* solutions to the Bike task were categorised approximately across ST, DT or both ST and DT, as shown in Table 1.

Table.1. Comparison of teachers' foci when providing feedback on the *correct* and *in correct* solutions to the Bike (standard) task

Teachers' names	Teachers' *foci* on Chris's (correct) solution	Teachers' *foci* on Rob's (incorrect) solution
Ms Jenkins		
Mr Jackson		
Ms Johnson		
Mr Robinson		
Mr Geraldton		
Mr Peterson		
Mr Pierce		
Ms Chick		
Ms Jones		
Mr Sadler		
Mr Richardson (no comment)		

Note: DT= Disciplinary Thinking, ST= Student Thinking. Where I coded the responses to be between A & B, I judged the teacher's attention to be on both DT and ST. Where I coded the responses to be on A, I judged the teacher's attention to be on both DT and ST but inclined to DT. Where I coded the responses to be on B, I judged the teacher's attention to be on both DT and ST but inclined to ST.

Each teacher's feedback on two students' (*Chris* and *Rob*) solutions to the standard (Bike) task indicated that the focus of individual teacher feedback varied according to the type of student solution. Table 1 shows that eight teachers attended to both ST and DT when they provided feedback to *Rob's incorrect* solution, while six teachers feedback indicated the focus of both ST and DT, when attending on Chris's *correct* solution. When teachers' feedback has the same focus on a student solution or explanation of the formula, the nature or detail of their comments was different. This suggests that the teachers' Pedagogical Content knowledge(PCK) differed.

With regards to Chris' solution, Table 1 shows that six teachers' feedback fell into both ST and DT, and a small group of teachers' comments were described falling under DT. Mr Richardson did not provide sufficient comment, as he just stated "well done" when providing feedback on Chris's solutions. Thus, his feedback was not classified.

Selected excerpts from teachers' written and verbal responses are outlined below. For example, Mr Pierce's feedback to Chris's solution is listed under the DT category. He wrote,

… I would suggest, once Chris establishes this question is about a falling object, he should *list the data* he has available as well as assumptions, E.g. g = 10 m/s^2, $v_{0 = 0}$, and the *equations* available. Then he can select the appropriate equation based on the data available.

Mr Pierce emphasized only the data and algorithms used in task, and the process of problem solving, which is an example of a DT focus. However, Ms Chick believed that Chris's oral expression needed to be improved, as this is evident from her written comments:

Spend time helping him *verbalize* his answers; he showed excellent *understanding* of the concepts but just needs *help to put it into word...*

Ms Chick added in her interview as follows:

…And I get the impression here that he's repeating without showing any understanding. She needs to apply it and she needs practice applying it, and whether that's written down initially or initially *talking her way* through it *through group work,* she needs practice.

Ms Chick highlighted Chris's difficulty in verbalizing the answer, which other teachers did not specifically point out. Ms Chick, overall, attended to both ST and DT, when providing feedback to Chris's solutions, which is consistent with her interpretation of Chris's solutions, which attended to both ST and DT. Similarly, Ms Johnson's feedback to Chris's solutions fell into both ST and DT categories, but her priorities to provide a feedback are varied. For example, she wrote
Mostly I would suggest Chris starts by *thinking* and *imagining* the object rather than starting with I need some formulas! So I would use a diagram and *think aloud with him about what is actually happening first*, then get him to list the relevant data before selecting an equation. I would also *get him then to decide* if his answer was reasonable for the problem described (value and accuracy).

This comment clearly shows that she leads Chris to understand and think about the process of solving the task (see the italicised words). In other word, while Ms Johnson attended to both ST and DT when constructing feedback to Chris, she has specific emphasise on ST, which is similar to the perspective she had used when interpreting Chris's solution

With regards to *Rob's* solution, Each teacher feedback on *Rob's* solutions to the Bike task were categorised approximately across ST, DT or both ST and DT in Table 1. While most of the teachers' feedback on *Rob's* solutions have a dual attention to both ST and DT, three teachers attended to DT. Mr Peterson's written comment on *Rob's* solutions is an example of feedback indicating a focus on DT:

What motions are occurring during the fall of the tail light what forces are acting and in what directions? What would happen if the bike was stationary? What factors would influence how long it took to fall when stationary? If the light did not break free where would it be each second? Draw successive positions of the fall in both these cases. Describe the continued motion. What influences the time it takes to fall? what influences how far along the road the light travels. What are the four equations of uniformly accelerated motion? How would you apply these? Also relate back to d versus t graph for uniform velocity and uniform acceleration. Solve again.

A close analysis revealed that Mr Peterson was re-presenting *Rob's* explanation or performance, rather than interacting with *Rob's* explanation and thinking when interpreting *Rob's* solutions. Mr Peterson provided a detailed explanation with much content when providing feedback on *Rob's* solutions to the Bike task. Feedback with a lot of content and information may of course confuse or discourage the student. This was suggested by Sanders et al. (1993) who conducted research on a momentum topic, and stated that even though, in some instances science teachers were aware of students' difficulties, they used too much detailed explanation of the content and this confused both themselves and students.

Ms. Jenkins attended to both DT and ST when she interpreted *Rob's* solutions.

It is a good strategy to link a question to a previous question. However, the problem Rob has is that he does not fully realize that velocity has a vector nature and that the motion in the vertical and horizontal directions are independent of each other. Rob's maths would be perfectly appropriate if he realized that it is only the vertical motion that is important, and that in the vertical direction the initial velocity is zero.

The above excerpt indicates that Ms Jenkins was interacting predominantly with *Rob's* (student) explanation and strategy to solve the Bike task, rather than just re-presenting *Rob's* thinking and explanation. She also focused on the source of *Rob's* errors in the context of the motion task.

To summarize, the above results suggest that each teacher's feedback on student solutions to motion tasks, is unique. For instance, it was shown that the focus of individual teacher feedback varied according to the type of solution. This suggests that each teacher's PCK is dynamic and responsive to different teaching situations. Although this is embedded in the idea of a teacher's skilled knowledge or PCK as suggested in some literature (Shulman, 1986), itwas in this case expected. This research provides examples that illustrate the nature of teacher knowledge viz. how the representation of formal physics concepts and knowledge about responses to student thoughts/views interact.

6. Discussion

Although the assumption in this study was that dual attention to both Student Thinking and Disciplinary Thinking would promote meaningful problem solving by students, this was not always the case. This highlights the importance of teachers having the appropriate skilled knowledge and understanding of both content and student learning in order to promote student understanding of concepts and use of meaningful problem solving strategies. In this section, we firstly discuss factors related to teachers' feedback and then explain differences in feedback among teachers who gave dual attention to both ST and DT.

6.1. Factors Related to Teachers' Feedback

As explained in introduction, a focus of this study is on improving students 'learning difficulties when solving linear motion tasks. Thus, it is important to employ closer analysis of the teachers' feedback on *Rob's incorrect* solution and his difficulties. Through a detailed discussion of the results, all teachers' feedback on *Rob's* solution are grouped, and explained below.

(1) To some teachers (e.g., Mr Peterson, Mr Richardson, Mr Geraldton, and Mr Pierce, Mr Jackson), their beliefs about the teaching and learning of motion problem solving, rather than specific content knowledge were more consistently reflected in their written feedback. The mastery of these teachers' dispositional knowledge or beliefs about teaching motion tasks and the use of the formulae seem to structure their feedback. In this group only Mr Peterson showed a rich Content Knowledge (CK)in the area of linear motion, and his beliefs about teaching and learning problem solving seemed to be the main prompt for his focus on Disciplinary Thinking conveyed in his feedback on *Rob's incorrect* solutions. It is interesting that despite his 35 years teaching experience, Mr Peterson did not attend to Student Thinking. His PCK, as reflected in his feedback, was shaped by beliefs about teaching motion tasks and the use of the formulae that were grounded in the authority of the physics discipline, as represented in curriculum materials. Four teachers (Mr Geraldton, Mr Richardson, Mr Pierce, and Mr Jackson) who showed a poor CK in the area of linear motion, attended to both Student Thinking and Disciplinary Thinking in their feedback, which is consistent with their focus, when explaining their beliefs about teaching and learning motion. Although Mr Jackson's beliefs about teaching and learning motion were not classified in any specific category (see 5.3.4), the detail and nature of his beliefs were reflected in his feedback.

(2) To some teachers (Ms Jones and Mr Sadler), there was no strong relationship found between their feedback and their beliefs about teaching and learning motion. This is consistent with Pajares' (1992) observation that: "Beliefs strongly influence perception, but they can be an unreliable guide to the nature of reality" (p.326). Here, the perceived reality was the necessity of 'correcting' grammatical misrepresentations in student responses. We feel that these teachers' reported beliefs about teaching motion tasks and the use of the formulae were 'unreliable guides' to interpreting their suggested feedback. Although Ms. Jones was predisposed to a belief that she should attend to both Student Thinking and Disciplinary Thinking with respect to the learning and teaching of motion, her feedback was focused only on Disciplinary Thinking. This may have been related to her low CK and/or lack of experience in explaining the meaningful use of the formulae. While Mr. Sadler's beliefs about learning and teaching motion were brief and vague, he attended to representation of the content used, and/or the process of problem solving and experiment when providing feedback. This may be related to his low CK and/or having fewer years (three years) of experience in teaching physics.

(3) For some teachers (e.g. Ms. Chick, Ms. Johnson, Mr. Robinson, and Ms. Jenkins) both their CK and beliefs about the teaching and the learning of motion problem solving were associated with their attention to both ST and DT in their feedback. These teachers were predisposed to linking knowledge and practice to meaningful understanding of the formulae and their teaching of physics problem solving. They attended to both Student Thinking and Disciplinary Thinking in a way which could be described as a dialogical conceptual change strategy. All the teachers showed a rich CK in the area of linear motion.

Generally however, we have found in this study that teachers' content knowledge and their beliefs about the learning and teaching of motion to be related without either being the determining influence in teachers' responses to students.

6.1. Differences in Feedback of the Teachers Who Had Rich Content Knowledge

Consideration of the last group suggests that both rich Content Knowledge (CK) and beliefs about the meaningful use of formulae in problem solving influence teacher feedback on student misconceptions. However, the nature of their beliefs matters as illustrated by the example of Mr. Peterson. In the first group of teachers above, Mr. Peterson's CK was considered as being at a rich level, but both his beliefs about teaching and learning motion and feedback were focussed on Disciplinary Thinking (representation). It appeared his rich CK did not automatically dispose him to attend to Student Thinking about the discipline of motion in his feedback, nor did his many years of teaching experience. He did not believe that students would have difficulty using and understanding graphs that 'good' physics teaching could not prevent. This highlights the importance of teachers having the appropriate skilled knowledge, awareness, and understanding of both content and student learning in order to promote student understanding of concepts and use of meaningful problem solving strategies.

While the first assumption of this study was that dual attention to both Student Thinking and Disciplinary Thinking would provide a meaningful feedback, this was not always the case as this is exemplified below.

6.2. Differences in Teachers Feedback Which Had Dual Attention to Both ST and DT

A close analysis of thinking and reasoning of the teachers whose feedback attended to both Student Thinking and Disciplinary Thinking have been conducted to explore and differentiate teachers intentions and beliefs about teaching and learning motion tasks. These teachers' (Ms. Chick, Ms. Johnson, Mr./Robinson, Ms. Jenkins, Mr. Geraldton, Mr. Richardson, Mr. Pierce, Mr. Jackson) comments are grouped, and explained below.

Group 1 included two teachers (Ms. Chick, Ms. Johnson), who had rich content knowledge, attended to both Student Thinking and Disciplinary Thinking in their responses to students difficulties providing a careful articulation of a well developed sequence of ideas. Their responses reflected their deep understanding of the content, and demonstrated their capacity to apply this knowledge and beliefs about problem solving and the use of formulae in ways that made those ideas meaningful and specific for students. For example, Ms. Chick's beliefs about teaching the application of formulae to problem solving were expressed as skilled knowledge of the students' development of individual understanding of the content and the process of problem solving in this area. This predisposed her to integrate both Student Thinking and Disciplinary Thinking to offer a logical justification of her argument, rather than superficial and general commentary, and provided specific feedback.

Group 2 included the feedback responses of the other six teachers who gave dual attention to Student Thinking and Disciplinary Thinking and not expressed as meaningful problem solving strategies and did not offer specific feedback. Amongst these teachers, two teachers had rich CK (Group 2a) and four teachers (Group 2b) showed poor CK in the area of motion. These are detailed and discussed below.

Group 2a: Although Mr. Robinson and Ms. Jenkins had rich CK, their content knowledge did not offer meaningful or specific feedback. Their beliefs about problem solving attended to mathematics aspects of the task rather than attending to meaningful problem solving. For example, when providing feedback, Mr. Robinson asked several systematic questions about problem solving strategies, but did not use his rich CK to provide specific questions that scaffolded meaningful problem solving. While the assumption of this study was that teachers who have high content knowledge and attend to both ST and DT in their feedback, they would develop meaningful feedback, this was not the case with these two teachers. The current study suggests a relationship between teacher dispositional knowledge or beliefs about teaching problem solving and the nature of their interpretations and feedback on student solution of motion task that may be more complex than has been assumed.

Group 2b: Four other teachers (Mr. Geraldton, Mr. Richardson, Mr. Pierce, Mr. Jackson), who attended to both ST and DT, did not show rich CK in the area of motion, and either their content knowledge or poor strategic thinking limited their feedback. For some, their strategic thinking about the teaching and learning of motion informed their feedback, but their low CK in the area of motion limited their ability to integrate ST and DT to provide a meaningful problem solving strategy. Mr. Geraldton, Mr. Richardson, and Mr. Pierce fell into the first group(see previous part of Discussion section). The beliefs of these teachers referenced general pedagogical theory and formal Newtonian theory. However, their responses were not directed to "the development of qualitative understanding"; instead their feedback was concerned with the significance of "quantitative methods of representation and algebraic methods of solution" (Hobden, 1998, p. 229). Their feedback drew on general perceptions of ST and DT which they did not integrate in their feedback. Their feedback seemed to be directed at explaining how to get the right answer to a specific problem, not to supporting students' ongoing learning. Teachers such as Mr. Geraldton, who believed that students' mastery of physics concepts in motion problem solving can be directly read from their test or exam results, spoke of the challenge for physics teachers to transmit the formal concepts to get the *correct* answer, rather than attending to understanding the physical relationships described in the task. Mr. Jackson wrote:

Work on *visualizing* situations would be good. Using a calculator should be second nature! As with Rob, Chris also need to get involved doing practical work with balls dropping and being projected would help this aspect. The use of videos/DVD or applets to help develop the concepts of the independent motion is required. *Plain old hard* work and *repetition* through multiple examples/problems is paramount.

This comment shows that Mr. Jackson's priority in constructing feedback is building upon motion experiences, and visualizing the situations. It seems that Chris's performance probably influenced the last statement in Mr. Jackson's comment above. However, his comment is consistent with a traditional teaching emphasis and indicates a focus on Disciplinary Thinking. He surprisingly used the same written feedback on the *incorrect* solutions of *Rob* to the Bike task, which was a unique case in this research. This is different to what might have been embedded in the theoretical perspective of this paper. It might have been expected that his feedback would be varied to different student solutions, views, and needs, that is, he would show that he could respond differently to different student constructions. His beliefs about teaching the motion topic also showed that he focused on his own understanding of the motion topic, rather than responding to student misconceptions or views about the motion topic. In short, our discussion of the differences in the feedback of the eight teachers who attended to both ST and DT related to the teachers' employment of language generally, and more specifically to their reasoning about student needs and/or understandings of the formal physics concepts, where an understanding of the use of mathematical models was required.

In summary, dual attention to ST and DT is also not simply a characteristic of teachers with rich content knowledge. The nature of teachers' feedback to student difficulties were strongly reflected the nature of teachers' beliefs about teaching and learning motion. However, the nature and type of teachers' feedback did not have strong association with teachers' level of propositional knowledge, or their teaching experience.

7. CONCLUSION

A unique feature of the research design was the use of surrogate student solutions, which permitted a comparison between teachers on the same student text. It was shown that the focus of individual teacher feedback on student solutions varied based on the type of solutions. This suggests that each teacher's pedagogical content knowledge is dynamic and responsive to different teaching situations. Although this is embedded in the idea of teacher pedagogical content knowledge, which embraces both content knowledge and dispositional knowledge or beliefs, and was expected, the reported data provided specific examples of teachers' knowledge and their reasoning in representing formal physics concepts and responding to student thoughts/views. A major finding of this study is that teachers' feedback on student responses could be categorised in terms of the extent of their dual attention to Student Think in grand Disciplinary Thinking, which form a dynamic 'conversation' between these two categories.

7.1. Implication for Teaching and Curriculum

It has been shown that teacher skill in discussing the use of motion formulae in the physics context is explicitly shown to be an important issue (Sherin, 2001). This to a large degree should define teachers' thinking about constructing good physics teaching practice, particularly, their feedback on student difficulties in the standard linear motion task. Thus, commitment to teaching meaningful problem solving and understanding of the use of kinematics formulae in linear motion is important to be considered by teachers and pre-service teachers.

The central theme of this study was not to investigate the use of discursive practices for teaching motion problem solving in physics. However, the argument presented in this research recognises the need in practice and research to consider how educators might better examine and critically reflect upon communicative language of teaching and pre-service teachers' reasoning in classroom discourse in the area of feedback to students. The dialogues embodied in the written feedback communicate to students the kind of teacher thinking and emphases. It might mean that teachers reform their ways of providing feedback by making it explicit to the leaners. Whichever focus conveyed must be purpose driven and made explicit to the learners. For instance, teacher educators need to investigate and identify pre-service teachers' beliefs about the use of mathematics, such as kinematics formulae or graphs in physics, and discuss this notion in relation not only to the motion topic but also to a philosophy of physics.

7.2. Methodological Implications for Further Research

This study has developed a framework for exploring some aspects of physics teachers' knowledge in the motion topic through using an approach explained in the Method section. The findings of this research showed that the questionnaire and interview have the capacity to reveal subtle differences between teachers' responses, which leads to revealing the differences in teachers' pedagogical content knowledge. This could form a background for a larger study, where pedagogical content knowledge could be examined in the context of teaching physics or other subjects. Many descriptions and characteristics of ST and DT categories were provided, with respect to the teachers' feedback on student responses to the linear motion tasks (refer to Appendices B and D). This could be used as an analytical template or a diagnostic tool, to lead any instructional interventions, apply curriculum development, or to be employed in further research to examine, interpret and understand teacher feedback, beliefs and pedagogical thinking.

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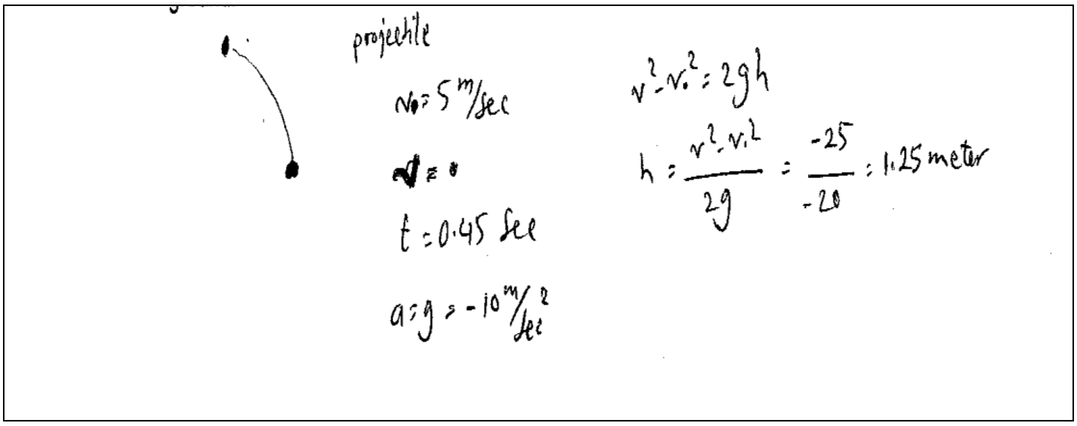
Appendix A

- Please discuss Rob and Chris thinking and strategy (ies) in solving the "Bike" task, especially in terms of the mathematics used, reasoning and physics understanding.

- Explain what feedback you would give to each student about their thinking and strategies he/she used in solving the problem.

Rob: I remembered a problem that I had done about dropping an apple from an out stretched hand when driving a car. I considered the initial velocity was the initial velocity of the car, so in this case of the bike that would be 5 m/s. Its final velocity when it hits the ground is zero. It takes 0. 45 seconds so that is the time; a is g which is negative, so -10m/s^2. Then I used v^2-v_0^2= 2gh. I rearranged for h and substituted giving me minus 25 over minus 20, which is 1.25 metres.

Rob's work sheet:



Reference: Parvanehnezhadshirazian, 2011, p. 134.

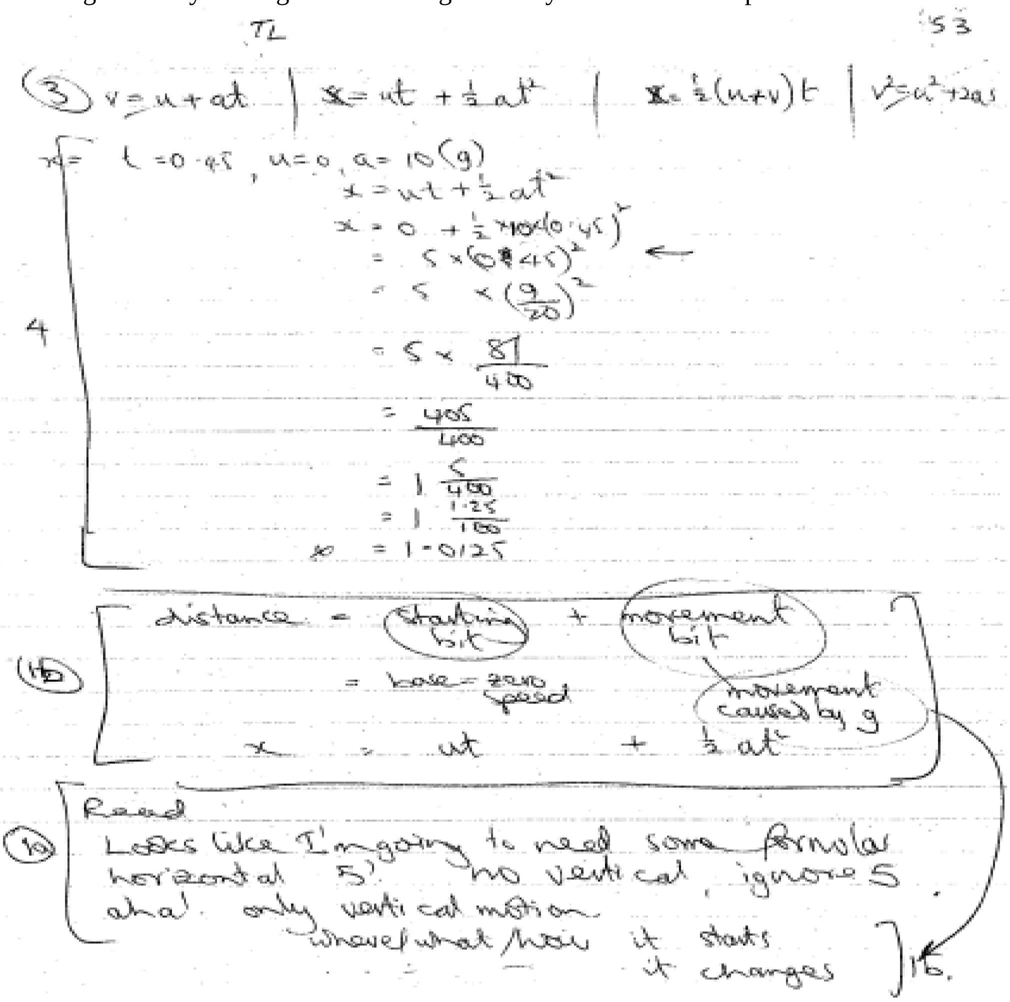
Figure 1: Rob's solution.

Chris: Firstly I was reading [the problem], then I needed some formulas. Then

I'm thinking horizontal 5. No it is vertical so ignore the five, that was my next bit of thinking.

Int: Did you go quickly to this equation, or…

Chris: No then I thought so it is vertical, where?, what?, how it starts?. Then where? What how it changes. So that bit [indicating "movement caused by g"] is really here [draws an arrow to "Where/what /how it starts and Where/what/how it changes"]. I thought, aha, it is only vertical the motion I am looking for a distance. I have to know something about where I started and since it is a vertical distance, I know that … acceleration is going to take effect so I know there is going to be something related to where I started which is not given by the distance but it is given by the speed. Something about how I was going to get faster. So that was my beginning, something about my starting and something about my increase as it drops.



Reference: Paravanehnezhadshian, 2011, p. 131.

Figure 2: Chris' Solution.

Appendix B

Table 1. The feedback indicated the focus on Disciplinary Thinking (DT)

Codes	Characteristics	Examples
DT/C/ P.S OR	**Teacher's focus on their need or interest of the content used in P.S or Eq:** The teacher attended to asking about and/or explaining the content that he/she wants student to learn, not the content that the student needs to understand, when providing *feedback*.	Ms Chick said: "…I introduce some patterns of P.S strategy which usually represents in the final exams…" (Interview) **Comment:** Ms Chick's priority was teaching the specific content used in the exam.
DT / C / Eq	**Teacher's focus on importance of the Content used in P.S or Eq:** The teacher attended to their teaching of the content, not on the student learning the content, when providing *feedback*.	Mr Robertson said "…Why did you select that formula? Why is it appropriate? Why did you manipulate The numbers around rather than using your calculator? How did you know it was only the vertical motion that was important?..." **Comment**: he focused on detailed explanation of the content.
DT / P/ P.S OR	**Teacher's focus on need or interest about Process of P.S or Eq:** The teacher attended to the student performance, rather than student thought, when providing *feedback* on the process of student P.S	1- Mr Robertson said: "…when are these formulas appropriate? How many directions of motion can be considered in the equation? What forces are acting on the tail light? What direction is the force(s) acting? What are you being asked to find? … A very good effort! …" 2-Mr Peterson also said"…ask how to apply the vector equation to this case".
DT / P/Eq	**Teacher's focus on the Process of P.S or Eq:** The teacher attended to routine teaching procedure (for the process of P.S), not focus on the student learning/thoughts, when providing *feedback.*	Using routine teaching strategy by Mr Jackson, Mr Geraldton, and Ms Jones as below: 1- Rehearsing algorithms, 2-using formulae as given. 3- Focussing on to "...Writing unknown and unknown…"
DT / J / P.S OR	**Teacher's focus on his/her need/ interest of P.S or Eq, when justifying the *feedback*:** The teacher attended to his/her own needs or interest , when justifying the *feedback* in terms of, the Content used in, or the Process of the P.S or use of the formulae.	Put Peterson interview of teaching graph

DT / J / Eq	**Teacher's focus on importance of teaching the P.S strategy or use of Eq when justifying the *feedback*:** The teacher attended to justifying the role of their teaching content, not on the student learning of the process/content of P.S, when providing *feedback* to student solution.	Mr Peterson said: "…that that's bad teaching [of graphs], in the same way some of the misconceptions in science whether it's motion, …, is bad teaching because they haven't taught the basic concepts…" **Comment:** Mr Peterson's justification or reasons indicates to the role of the teacher in classroom

C= Content, P= Process, J= Justification of the suggested feedback, P.S = Problem Solving, Eq= equation
Reference: Parvanehnezhadshirazian, 2011, p. 237-241.

Table 2 . The feedback indicated the focus on Student Thinking (ST)

Codes	**Characteristics**	**Examples**
ST / C /P.S OR	**Teacher's focus on a general idea about student need, as he/her referred to the content used P.S & Eq:** The teacher attended to the student background knowledge, when providing *feedback*.	Mr Geraldton said: "…Rob firstly needs to have confirmed the correct aspects of what he understands…"
ST / C /Eq	**Teacher's focus on importance of learning the process of P.S & Eq:** The teacher attended to the student learning, not their teaching of the content, when providing *feedback*.	Ms Chick modifies incorrect intuitive knowledge by linking maths and physics knowledge to help student learning. (interview)
(ST/ P / P.S) OR	**Teacher's focus on general idea about the student need, as he/she referred to the process of P.S or use of Eq:** The teacher attended to the student thoughts about the process of P.S , rather than attending to student performance, when providing *feedback* to student solution.	Mr Geraldton said: Rob …. is not completely wrong and there is a lot to be gained in building his confidence based on what he knows. **Comment:** As a result; the teacher appreciates and acknowledges the student understands of the content, rather than criticising student performance.
(ST/ P / Eq)	**Teacher's focus on importance of learning the process of P.S & use of Eq:** The teacher attended to the process of the student understanding of the process of P.S, rather than to the procedure of teaching the content.	Mr Geraldton said: "…Rob firstly needs to have confirmed the correct aspects of what he understands. …" **Comment:** As a result; the teacher suggests (the) ways to make student realizes his/her own fruitful thoughts and how helps him/her develop competence/ mastery.
ST / J /P.S OR	**Teacher's focus on general idea about student need, as he/she justified the *feedback*:** The teacher attended to student thoughts or need, when justifying of his/ her suggested *feedback*	Mr Geraldton said: "…I know that it is difficult for students… to understand equation, so I would not to define the equation for my students…"

ST / J /Eq	**Teacher's focus on importance of learning the P.S & Eq:** The teacher attended to the importance of learning of the process or content used in P.S/Eq, when justifying his/her suggested *feedback*.	Mr Geraldton said: … "Again, he needs to be confirmed in his acquired understanding. Talking yourself through a mental image of the situation (which Chris seems to do) is a good strategy to maintain. **Comment**: The above statement indicates of Geraldton's a justification was based on of the Chris learning of imagination of the problem situation.

C= Content, P= Process, J= Justification of the suggested feedback, P.S = Problem Solving, Eq= equation
Reference: Parvanehnezhadshirazian, 2011, p. 242-247.

Appendix C: A summary of Mr Geraldton's feedback on:

- Three students (Rob, Chris & Sue) solutions to standard (Bike) task
- Three students (Mary, Michelle & Simon) explanations of the formula $v = v_0 + at$
- Two students (Karl & Mike) solutions to non-standard (Shoved Block) task

signs/ codes	focus of codes	Teachers' foci on 8 students' solutions							
		Rob	**Chris**	**Sue**	**Mary**	**Michelle**	**Simon**	**Karl**	**Mike**
DT/C/Eq	focus on DT				x				
DT/C/P.s		x √						√	
DT/P/Eq	focus on DT								
DT/P/P.s		x√	x					√	
DT/J/Eq	focus on DT								
DT/J/P.s		x √						√	
ST/C/Eq	focus on ST				x	x	x		
ST/C/P.s		x√	x	x					
ST/P/Eq	focus on ST								
ST/P/P.s		x	x	x					
ST /J/Eq	focus on ST				x	x	x		
ST/J/P.s		x	x	x					

Reference: Parvanehnezhadshirazian, 2011, p. 255.

1-P.s= Problem solving, Eq= Equation, DT= Disciplinary Thinking, ST= Student Thinking, C=Content, P=Process, J=Justification.

2- Each x and√ indicates the data from questionnaire and interview, respectively.

3- Each x or √ indicates at least an incidence of the component of either Disciplinary Thinking or Student Thinking categories, when teachers provided feedback on the students' solutions.

Appendix D: Coding and Contextual Units

Table1. Examples of coding and contextual unit with respect to teacher interpretations of student solutions

Area of attentions	Examples	Examples of smallest elements indicating ST
content	- Correct answer(accurately) - getting wrong answer - use/ apply the content correctly	-visualising - understanding content
process of use of formula or solving problem	- Identify the appropriate equation - used the appropriate equation - Recognising that there was both horizontal &vertical… - She organised the information	-Understanding the appropriate equation -Searched the appropriate equation -He need to be nurtured and built upon
diagnosing source of student's error	-She/he has been taught -referring to the new content such as vector to diagnose student error -teacher focused on correctness or incorrectness of content/ strategy of P.S or the answer to diagnose student error	-She/ he has learnt -asking different question to find student's background knowledge -He has logical approach He is very bad at expression her understanding

Note: DT = Disciplinary Thinking, ST = Student Thinking, underlined words show teacher attention to ST or DT

Table 2. Examples of coding and contextual unit with respect to teacher feedback on student solutions

Areas of attentions	Examples of DT	Examples of ST
the content used in the feedback	- discussing on new knowledge, and new task/ experiment E.g., Giving more problems / experiments with variety (to Chris) to get confidence	-discuss on Student's background knowledge, and current task/ experiment giving a couple of further similar problem for reinforcement Try to build their confidence
	- "ask about the content (e.g., Velocity)"	-let them know/ refer to Velocity -Allow students to think about velocity to get him to imagine
process of P.s used in the feedback	doing experiment/s	-we work on the current task to improve -let students to do or create experiment -Discuss on the process of current task, [rather than new task] - I would ask him to explain what he understands
justification of the suggested feedback	I like to use vector	to students is important to get the right answer not understanding equation" -follow up with a similar problem to be worked through, to see if he has made the required change in his thinking

Note: DT = Disciplinary Thinking, ST = Student Thinking, underlined words show teacher attention to ST or DT

Table 3. Some examples of coding and contextual unit with respect to teacher beliefs about teaching and learning motion

Areas of focus	**Examples of DT**	**Examples of ST**
Content	I like to explain about vector in my teaching	We do …based on something that student experienced before
Process	- Routine teaching	I use different approach in my teaching, based on the student's ability We solve this …
Justification	-Expectation for getting correct answer to be ready for exam -PT :"I like to use graph, because it is easy …"	-Expectation of understanding to be ready for exam

Note: DT = Disciplinary Thinking; ST = Student Thinking, underlined words show teacher attention to ST or DT

Reference: Parvanehnezhadshirazian, 2011, p. 269-271.